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Virtual Field Trip for Mobile Construction Safety Education Using 360-Degree Panoramic Virtual Reality*

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Construction safety education plays a vital role in equipping students with concrete safety knowledge and promoting safety performance prior to entering construction sites. However, safety topics are not given adequate attention in most construction curricula and traditional pedagogic tools fail to provide practical experience or sufficiently engage students in acquiring safety knowledge. With this regard, this study proposes the VIrtual FIeld Trip System (VIFITS) for mobile construction safety education using a 360-degree panoramic virtual reality. The VIFITS utilizes a state-of-the-art 360-degree panorama-based Virtual Reality technology in order to bring construction field trips to the classroom and provide practical experience to improve students' safety knowledge. VIFITS consists of three modules: (1) a Safety Information Dissemination module (SID) in which the educator disseminates safety information to the students through mobile learning; (2) a Virtual Field Trip Experience module (FTE) where students experience virtual construction field trips based on their own mobile devices; (3) and a Safety Knowledge Assessment module (SKA) designed for learners to play testing simulation games in order to assess their safety knowledge. The VIFITS prototype is developed and validated with virtual scenarios derived from real construction sites. The results reveal that the VIFITS is a powerful pedagogical method for effectively providing practical experience and safety knowledge for students.

Keywords: construction safety education; virtual reality; 360-degree panorama; construction field trip

1. Introduction

Construction safety education at the tertiary level is very important for providing concrete knowledge and cultivating skills for students before they enter the construction industry [1, 2]. However, safety courses have not been given much attention at the universities [3] and some construction programs include safety topics in their curricula while others do not. Moreover, several studies have pointed out that current learning methods, which are lecturer-centred fail to adequately motivate and engage learners [4]. Consequently, students who have not acquired adequate safety knowledge tend to be more prone to unsafe acts at construction jobsites. Besides learning in classroom lectures, field trips play a significant role in providing students with practical experience while also motivating and engaging student's learning. Through field trips, construction students experience a real construction site and understand how construction activities are executed safely in practice [5]. However, it is difficult to organize adequate field trips for all students and courses due to the dangerous and complex nature of construction workplaces. Moreover, during such field trips, challenges such as ensuring student's safety and gaining access to sites are barriers to the student's acquiring safety knowledge [5]. The lack of field trips in current construction education negatively impacts on the learning outcomes at the tertiary level. Therefore, construction safety education needs an effective safety education tool to address these issues.

Virtual Reality (VR), which emerged over two decades ago has been applied and proven beneficial in various industries and educational disciplines. VR simulates computer-based 3D model to create artificial environments, in which users are immersed and able to interact with 3D worlds. However, 3D-based VR has limitations in terms of real-world visibility. In contrast, 360-degree panorama-based Virtual Reality (360VR) is able to overcome the shortcoming of 3D model-based Virtual Reality pertaining to real-world visibility. The rationale behind 360VR technology is a projection of spherical images to render the surroundings, where a camera view is positioned at the center of the image plane for realizing human-eye behavior. The spherical images are generated either from machine-aided applications (e.g., building information modelling) or from photographic imagery. In other words, 360VR presents not only captured scenes

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but also a modeling environment [6]. Field trips and construction site visit activities are of prime importance for construction safety education, however these face several limitations which hinder the knowledge acquisition of students. In response, 360VR has been considered as a potential tool that enables field trip visibility in the construction classroom.

One of the key enablers widely popularizing 360VR is web-based application approaches. Recently, the maturity of web programming languages (Spectrum) [7] and virtualized software as a service (SaaS) platforms promises a bright future for web-based applications. The main advantages of web-based 360VR are revealed as its operating system (OS) independent characteristics and device-capability adaptation. 360VR therefore is suitable for a variety of terminal screenings, including personal computer (PC) monitors, interactive kiosks, and especially mobile devices equipped with various display sizes. Nowadays, the ubiquitous use of mobile devices leads to many universities exploring a Bring your Own Device (BYOD) approach to mobile learning [8]. In terms of construction education, mobile learning has emerged and has afforded many advantages for construction students [9] through interactive learning environments, collaborative networked pedagogies and professional practice. Therefore, the combination of 360VR with mobile computing may present new opportunities for improving construction safety education.

With this regard, this study proposes the VIrtual FIeld Trip System (VIFITS) for mobile construction safety education using 360-degree panoramic virtual reality. VIFITS utilizes state-of-the-art 360-degree panorama-based virtual reality technology in order to bring construction field trips to the classroom and provide practical experience to improve students' safety knowledge. The proposed system provides an interactive learning environment based on the mobile devices of learners for mobile learning. VIFITS consists of three modules: (1) a Safety Information Dissemination module (SID) in which the educator disseminates safety information to the students through mobile learning; (2) a Virtual Field Trip Experience module (FTE) where students experience virtual construction field trips based on their own mobile devices; (3) and a Safety Knowledge Assessment module (SKA) designed for learners to play testing simulation games in order to assess their safety knowledge. The VIFITS trial is developed and validated with virtual scenarios derived from real construction sites. The results reveal that VIFITS would be a powerful pedagogical method to provide effectively practical experience and safety knowledge for students.

2. Related works

2.1 Current challenges in construction education

Before entering the actual industry, construction students must become knowledgeable and skilled in order to face the high-paced demands of the industry. Conventionally, university students acquire construction knowledge through educator-centered lectures, which take place in classroom environments. However, the effectiveness of traditional approaches has been questioned, and limitations have been pointed out repeatedly. Construction programs have been criticized for being passive and boring [10], insufficiently motivating [11], and lacking complex details [12]. Furthermore, in the context of safety education, the adopted teaching strategies and tools fail to provide realistic scenarios and problems that truly immerse learners and enhance learning [4]. In essence, a gap exists between how construction topics are disseminated in the classroom, and a real-world understanding of what happens on construction jobsites [13]. Consequently, graduates enter the construction industry without adequate safety knowledge due to a lack of exposure to real construction sites and processes during tertiary education.

In order to afford more authentic experience and exposure, learners are occasionally given opportunities to go on field trips, which encourage a more realistic perspective and understanding of construction work and its processes. Field trips are more learner-centered and allow students to experience a more holistic, integrated picture of construction methods and processes, which are typically presented through abstract textual and pictorial resources in the classroom. However, there are several limitations to organize field trips and ensure students effectively acquire the required knowledge. Aside from difficulties in finding construction companies and sites to host site visits, scheduling can also be logistically challenging [14]. Moreover, it is difficult to ensure students safety during construction field trips. Furthermore, construction jobsites are noisy, and students often struggle to hear and understand instructors during site trips. Oftentimes, this is further exacerbated by instructors' unfamiliarity with speaking to large groups. Consequently, learners become easily distracted, do not pay attention and thus fail to fully benefit from construction field trips [15].

2.2 Visualization technologies in construction education

Over the past few decades, advanced visualization technologies have garnered increasing attention in industry and education. Research efforts have considered the potential of virtual reality, virtual worlds, augmented reality and simulation-based techniques that represent real-life processes to improve the effectiveness of construction education and address the shortcomings of conventional pedagogic approaches. Several studies have considered visualization approaches to enhance construction safety education. For instance, Lin et al. [16] proposed a 3D safety inspector game and environment to develop students' hazard identification abilities. Similarly, game-based approaches have been considered to allow more engaging hands-on learning for trench safety education [17]. Le et al. [18] developed a model for construction safety training based on the second life virtual world platform, and then extended the approach and developed a collaborative virtual world-based platform to facilitate realistic construction jobsite visualization, role playing, social interaction and dialogic learning among learners [10]. Pedro et al. [4] utilized mobile VR simulations and games to integrate safety contents into construction education. Their approach improved captivation and engagement, and also effectively transferred safety knowledge to learners. Similarly, visualization technologies have been considered for building construction and construction quality education to improve educational content interactiveness and accessibility [5, 9]. These and other visualization-based applications have been found to have the potential to not only improve learning outcomes, but also afford benefits such as improved motivation, engagement, immersion and learner collaboration in various aspects of construction education.

2.3 Virtual field trips for construction safety education

Despite the potential of visualization technologies for construction safety education, the financial burden and time-consuming nature of virtual content development are still important issues. Virtual field trips are an alternative, more financially feasible approach, which have also been considered to conveniently provide learners with authentic exposure to learning environments. Scholarly efforts have deployed the virtual field trip concept in a variety of disciplines such as the life sciences [19, 20] and geography [21]. Virtual field trips have the potential to improve learner focus and engagement [22] without the time restrictions encountered in real-world field trips [23]. Meanwhile, in the context of construction education, research has been very limited. Jaselskis [24] developed an approach to deliver video imagery and voice information from real-time construction projects to construction engineering students. However, video and animation-based visualizations tend to be passive, as they do not actively engage learners in didactic activities. Moreover, there is a complete lack of research on the pedagogic potential of virtual field trips, specifically for construction safety education.

In response to this status quo, the VIFITS system proposed in this paper utilizes real-world imagery-based 360-degreee panoramic virtual reality to bring construction field trips to the classroom without the restrictive 3D and virtual content development costs associated with traditional VR. With the consistent rapid advances in mobile computing visualization capabilities, mobile devices with high speed internet, processing power, and high-res displays now offer unprecedented opportunities for learners to interact with didactic contents in new ways. The portability of mobile devices enables learners to access didactic contents conveniently and learn across different contexts. Moreover, mobile device-based learning inquiries tend to be personally relevant since learners can control what, where, and when they learn [25]. This creates a more adaptable learning model which affords access to multiple information sources, and a shift away from an authority-based learning structures towards a community-based structure [26]. Mobile learning enables not only the application of theoretical knowledge in a practical scenario, but also reflection on the applied knowledge [27]; however, few studies have considered mobile learning for construction pedagogy. Through mobile devices, the proposed VIFITS affords efficient and personalized field trips to provide practical experience and safety knowledge to construction students.

3. Framework

This section explains the overall concept and theoretical framework for VIFITS and describes its constituent features and modules. Fig. 1 depicts the VIFITS framework, illustrating a shift from the traditional learning approach to the proposed interactive 360-degree VR platform-based approach. The VIFITS framework comprises of three modules, namely the Safety Information Dissemination (SID), Virtual Field Trip Experience (FTE) and Safety Knowledge Assessment (SKA) modules. VIFITS proposes virtual construction field trips based on an interactive 360-degree panoramic virtual reality platform. Virtual construction field trips in VIFITS accurately represent the key learning steps that construction students would experience in real-world field trips in practice. For instance, SID illustrates the first step of a field trips namely meeting at the construction site; then FTE instructs students how to explore a construction field to obtain their knowledge as they do when visiting a construction site in reality;

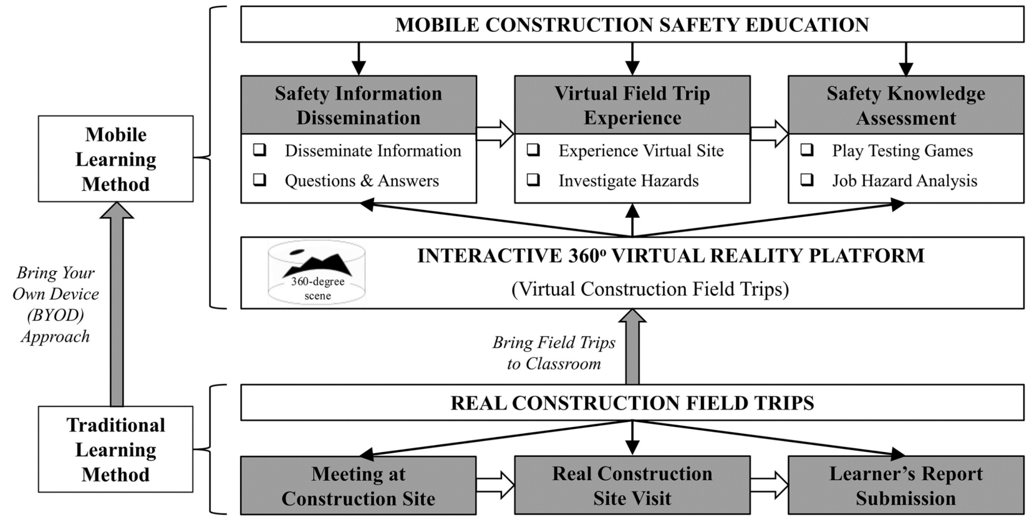


Fig. 1. VIFITS Framework.

finally, SKA simulates the final step of learners submitting reports after a field trip by assessing the safety knowledge of the students through VIFITS. FTE and SKA allow students to apply safety knowledge and skills such as hazard investigation and Job Hazard Analysis (JHA) just as a safety engineer would in practice, but within the interactive VIFITS. Moreover, through direct interaction with the learners' mobile devices, VIFITS adapts the Bring Your Own Device (BYOD) approach for mobile learning in order to assist learners conveniently by allowing them to study anytime and anywhere.

The following sections described each module in detail

3.1 Safety information dissemination module

During real construction field trips, a meeting takes place on site, whereby project managers provide students with safety information prior to entering the job site. In line with this approach, the SID module focuses on disseminating safety information to helps learners understand the status of the construction site before they move to the next step, allowing them to experience the virtual field trip by using their personal mobile devices. The information delivered to learners in this module pertains to: (1) the construction site and project characteristics; and (2) specific safety information, such as safety rules and hazards related to the work types and construction methods being considered.

The SID module is initiated with users logging in to the VIFITS system through their mobile devices. After that, by following the educator's instruction, students click the SID function, and then open a project introduction slide (Fig. 6b), which introduces safety information related to a virtual construction site that they will experience in the next step. This slide includes an additional teaching audio of the educator in order to assist students to follow safety lessons in the case of remote learning. Moreover, the educator also connects his mobile device with a projector to show the safety lesson slides on a big screen to effectively disseminate safety information in the classroom.

To ensure that students understand the safety issues presented by the educator, students partake in "question and answer" activities through a chatroom in VIFITS. The chatroom allows learners to discuss with their classmates online and raise questions until they thoroughly understand the safety issues discussed. To keep track of discussions and inquiries, usernames are provided in line with the questions, answers or remarks sent in the chatroom. In addition, the VIFITS chatroom assists users in uploading not only text, but also other supporting safety resources (such as links to videos, animations images and reference documents) to enable the comprehensive dissemination of every safety issue raised during the lessons. Through these features, VIFITS is designed to motivate and engage students in their learning. After the SID, students have an awareness of the status and safety issues of the construction site, which they will explore in detail in the virtual field trip exploration module.

3.2 Virtual field trip exploration module

With an educator's guidance, the FTE module provides students opportunities to obtain practical safety experience through a virtual field trip using their mobile devices. As shown in Table 1a, buildings are classified by floors (level 1) and by spaces (level 2) to assist learners to navigate through the virtual jobsite. This virtual building consists of many hotspots, which are defined as focus points and which can be interacted with, in order to identify hazards or access various safety contents. Hotspots are attached to specific building elements, which are classified based on the Uniformat classification, as shown in Table 1b. When learners click on a hotspot, the building classification and Uniformat classification are highlighted (Fig. 7a), allowing them to clearly visualize the building and address where they are in the virtual field trip. Moreover, through the touch screen functionalities of modern mobile and smart devices, learners can: zoom in, zoom out, and rotate their view to explore a virtual scene, and click on the building classification function in order to access every scene in the virtual building. Through this exploratory approach, learners can interact with various elements in the virtual construction site to obtain practical experience.

The hotspots are designed to represent safety information and e-materials related to specific elements to assist students in acquiring construction safety information. For example, students click on a video function of a hotspot to see how the construction process related to the element was executed at the jobsite. After understanding the construction method, learners investigate potential hazards during construction of this element by clicking on a construction hazard investigation function of the hotspot. This function provides many potential hazards related to a specific element in detail. As shown in Fig. 8, a construction hazard investigation template, which describes hazards/accident contexts, accident causes and prevention methods, is provided. Furthermore, this template includes links to the digital safety course materials, multimedia resources, and the Occupational Safety and Health Administration (OSHA) standards in order to provide learners with a holistic understanding of the hazard investigated. To consolidate safety knowledge, students are required to explore a virtual high-rise building and investigate other potential hazards by themselves. In addition to this self-learning stage, students discuss these topics with other online learners and the educator through the VIFITS chat room for further accident analysis until they clearly understand all potential hazards and safety issues during the virtual field trip.

In the FTE module, the educator plays the role of guiding the FTE processes, encouraging learners' discussion, and answering further questions. The aim of SID and FTE modules is to enable students to thoroughly understand safety issues in a construction site and acquire concrete safety knowledge prior to entering real jobsites. Moreover, the function of virtual field trip management (as shown in Fig. 11b) supports VIFITS admins and allows educators to easily add, remove or update virtual field trips in order to enable learners to experience different kinds of construction projects for safety education.

3.3 Safety knowledge assessment module

In order to assess the safety knowledge obtained from previous modules, the SKA module provides testing simulation games whereby students apply their hazard identification and Job Hazard Analysis (JHA) knowledge and skills, similar to how a safety engineer would inspect in practice. Prior to site inspection, general site information is available within the VIFITS environment to help students understand the status of the construction site. Once learners have a general understanding, they interactively explore the virtual construction site. Learners can conveniently zoom in, zoom out, and rotate in the virtual scene, as well as click on the building classification function to explore the virtual building. Students examine building elements and their related construction method videos to investigate and recognise potential hazards (Table 2). These hazards are designed to reflect the safety knowledge that students learned from both previous modules. Hazard identification is a crucial skill for preventing accidents in the construction industry. Hence, in the SKA module, learners cannot proceed to the next step until they have accurately identified all hazards in the current stage.

After the hazard identification step, students are required to answer questions for finishing a JHA report. The JHA report consists of the type of accident, hazard description, root causes of the hazard, and prevention methods to eliminate the potential hazard. VIFITS sends the complete mission notification for correct hazard identification and JHA to students. In addition, it requires learners to replay cases for any incorrect hazard identifications. Through this, VIFITS can stimulate and motivate students, while learning and acquiring safety knowledge effectively. The SKA also includes a countdown timer, which gives students a predetermined time period during which they are required to inspect the hazards embedded in the virtual scenario.

By role-playing as safety engineers to inspect hazards in a virtual construction field trip within the time limitation, SKA module aims to assess learners' safety knowledge and develop a comprehensive understanding of construction safety jobs for students, allowing them to perform safely in real construction sites.

4. System architecture

VIFITS has been developed using a web-based approach, hence, the system has client-server architecture where all of the core services and databases reside on a central server and can be accessed over a network through a web browser (i.e. the client, which provides user interfaces) integrated in mobile devices. In other words, the users only load information whenever they need it rather than permanently installing a complete heavy application. Fig. 2 illustrates the VIFITS system architecture in detail.

On the server side, although VIFITS independently operates on various underlying hardware infrastructures, an implementation of the system is proposed based on a cloud stack due to its advantages in scalability, cost-effectiveness, and high stability. The system has been designed within a service-oriented architecture (SOA) consisting of three distinct components including system features, system management, and a database. The system feature component provides functioning modules that interact with users through web interface, where the application layout module defines a standard set of interfaces for different user device capacities (e.g., screen, peripherals, and supported web engines); the projection, position, multimedia, and control modules render a 360-degree panoramic field trip featured via interactive hotspots and safety multimedia information; the classification module automatically maps the material corresponding to each hotspot to the material classification table; and the practice and learning record modules provide game-based assessment and recording services. For general system management purposes, the configuration and monitoring modules are developed to configure networking and operation parameters (e.g., internet protocol address, service sessions, and operation schedule) as well as monitor the system status. The service levels that grant access to various user groups are predefined by a service level agreement module. In terms of database management, the system separates the data into four categories (the system database, user database, safety material, and 360-degree panoramic field trip) according to different database access privileges.

On mobile devices, VIFITS provides all functions through a built-in web browser that is already integrated in most modern smart devices. Whenever a user accesses VIFITS, the application module first verifies the user device capacity based on its web engine information, assessing whether the web engine supports modern web presentation languages (HTML5 and CSS3) or only Adobe flash technology. Based on the verification result, XML configuration data are transferred back to the user device in order to provide responsive functions against varying screen sizes and available peripherals in order to deliver the most convenient user experience for system interactions.

5. Prototype design

VIFITS aims to provide real-world visualizations of construction sites through an innovative digital presentation approach. To this end, a combination of image capturing, processing, indexing, and exploitation plays an important role for the success of the entire system. VIFITS production can be broken down into three prominent operations: (i) 360-degree panoramic field trip rendering (i.e., content database generation); (ii) framework development (i.e., core services and standard application layout); and (iii) scene-based functions customization (e.g., hotspots positioning, safety information assignment, and learning record parameters instal-

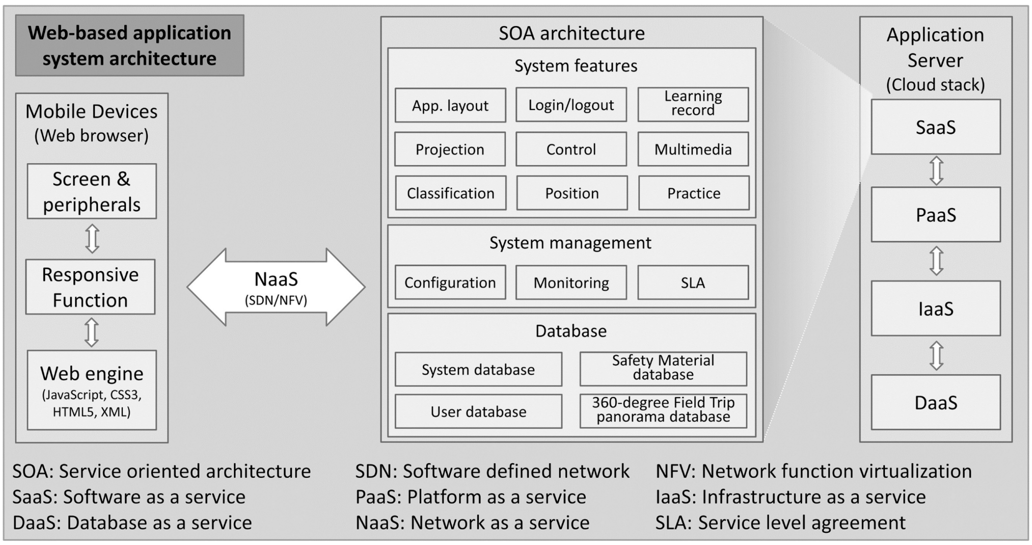


Fig. 2. VIFITS System Architecture.

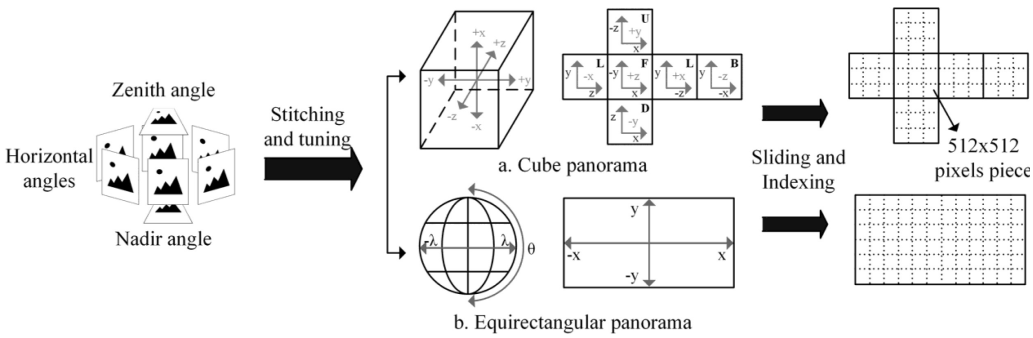


Fig. 3. 360-degree field trip rendering.

lation). Since framework development defines a standard environment and tools for system execution, it should be developed before serving users. In contrast, 360-degree panoramic field trip rendering and scene-based function customization should be considered as iterations where the content and corresponding functions are particular within each construction site.

5.1 360-degree panoramic field trip rendering

The 360-degree panoramic field trip rendering consists of three contiguous sub-operations: (i) construction environment capturing, (ii) 360-degree panoramic field trip stitching and tuning, and (iii) image sliding and indexing (Fig. 3). Nowadays, there are several methods and pieces of professional equipment that support the first two sub-operations manually or automatically [28]. In the scope of this paper, we generally describe the basic steps needed to reproduce a 360-degree panorama as follows:

- Position the camera at the intended spots within a height of 1.7-meter representing human eyes behaviour.
- Photograph the construction environment along the zenith angle, nadir angle, and all horizontal angles, ensuring a 360 × 180-degree field of view.
- Stitch subsidiary images into a 360-degree panorama (including a tripod mount point removing and visible quality tuning actions if needed).

The 360-degree panorama should be formatted in one of two typical types: cube and equirectangular. For virtual field trip projection purpose, these 360-degree panoramas are slid into 512 × 512-pixel pieces and indexed as *lx_d_xx_xx* rule, where *l*, *d*, and *x* denote the level, direction, and value, respectively.

5.2 Framework development

The VIFITS framework consists of a projection engine and a number of dedicated functions specified for the construction domain. To develop a VIFITS prototype, the KRpano [29] has been utilized as the projection engine due to its flexibility, high-performance (for panoramic images and virtual tours), openness, responsibility, and performance in supporting mobile user devices. In terms of web-based application presentation and programming, there are two technological approaches that should be utilized, HTML5 and Adobe flash. Although Adobe flash remains more popular in World Wide Web (WWW) applications over recent decades, its use involves significant issues in security and performance that are not appropriate for modern complex applications. Based on these concerns, HTML5 and its supported languages were chosen to pilot the VIFITS.

Figure 4 illustrates a development process where the 360-degree panoramic field trips database is exploited using web programming languages to build comprehensive and interactive 360-degree scenes. Within the HTML5 language family, HTML5 and CSS3 are utilized to provide a responsive and friendly interface to users, JavaScript

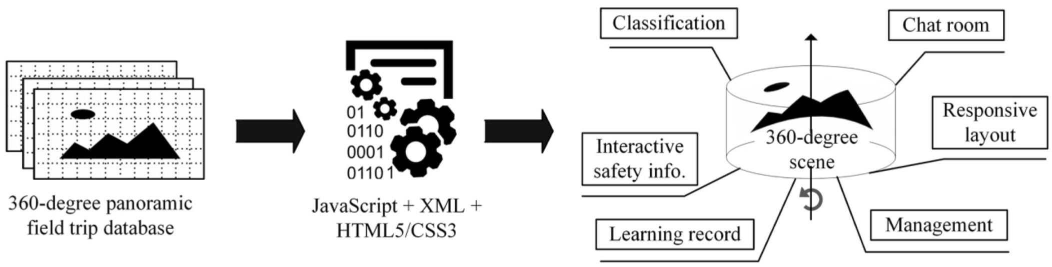
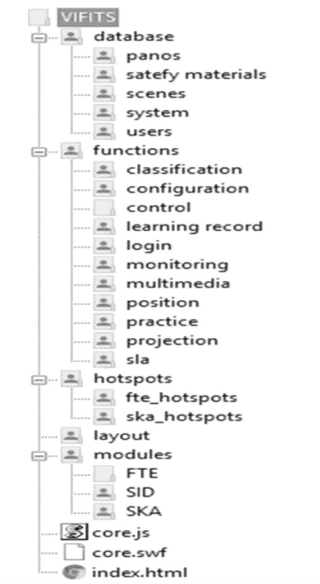


Fig. 4. Prototype development.



(a) VIFITS software structure

```
<!-- vfe hotspot -->
<layer name="materialcon" keep="true" type="container" width="94" height="32"  visible=
"false" align="lefttop" x="0" y="0" bgcolor="0xffffff" bgalpha="0.9" onhover=
"stopdelayedcall(spot);" onout="delayedcall(spot, 0.3, set(layer[materialcon].visible,
false); highlighteduniformat(););">
    <layer name="videom" style="material" keep="true" crop="0|0|100|100" align="lefttop" x=
    "1" y="1" onclick="youtubeplayer_open(get(youtubeurl)); set(autorotate.enabled,
    'false');"/>
    <layer name="imagem" style="material" keep="true" crop="100|0|100|100" align="lefttop" x=
    "32" y="1" onclick="set(layer[imagebox].visible,true);
    tween(layer[imagebox].width,50%,0.2); tween(layer[imagebox].height,50%,0.2);
    set(layer[imagecrop].url,get(layer[image1].url));"/>
    <layer name="ebookm" style="material" keep="true" crop="200|0|100|100" align="lefttop" x=
    "63" y="1" onclick=""/>
</layer>
<action name="hienthumb">
        sub(c, mouse.stagex, 0);
        sub(d, mouse.stagey, 50);
        set(layer[materialcon].ox, '-50%');
        copy(layer[materialcon].x, c);
        copy(layer[materialcon].y, d);
        set(layer[materialcon].visible, true);
        set(youtubeurl,%1);
        txtadd(temp,'%FIRSTXML%/materials/',get(xml.scene),'/',%2,'/image1.jpg');
        set(layer[image1].url, get(temp));
        txtadd(temp,'%FIRSTXML%/materials/',get(xml.scene),'/',%2,'/image2.jpg');
        set(layer[image2].url, get(temp));
        txtadd(temp,'%FIRSTXML%/materials/',get(xml.scene),'/',%2,'/image3.jpg');
        set(layer[image3].url, get(temp));
        txtadd(temp,"openurl('materials/",get(xml.scene),"/",%2,"/ebook.pdf', _blank);");
        set(layer[ebookm].onclick, get(temp));
</action>
```

(b) Sample XML code

Fig. 5. Scene-based functions customization.

defines the standard core services and functions based on the projection engine, and XML is used to customize parameters that are interchanged between HTML5/CSS3 presentation and JavaScript functions. As a result, VIFITS is characterized by classification, interactive safety information, learning records, chat rooms, a responsive layout, and management features on top of an underlying photorealistic 360-degree field trip. It is worth noting that VIFITS does not require any installation of a specific application on the user device side, except for a web browser with built-in HTML5 support.

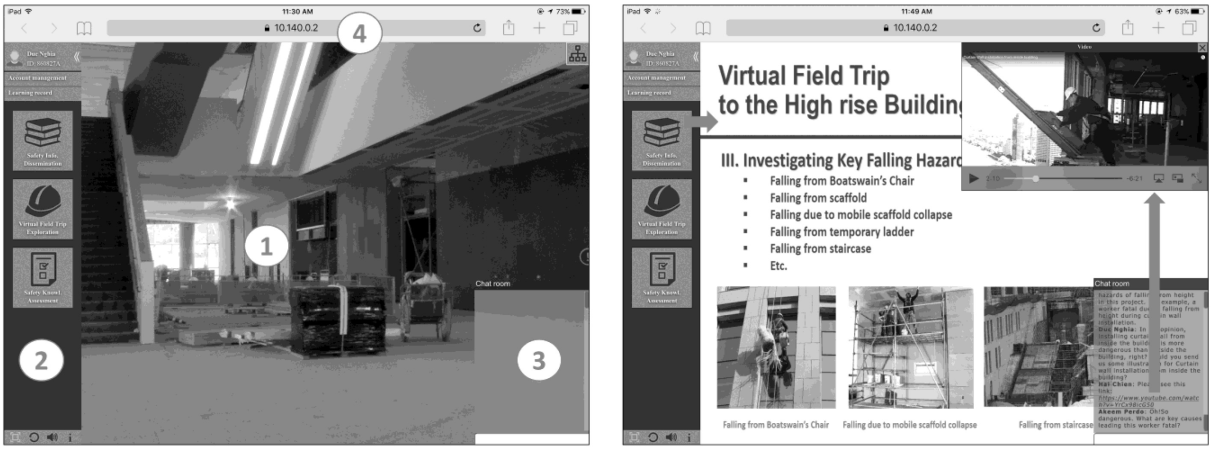
5.3 Scene-based functions customization

The hotspots positioning, safety information assignment, and learning record parameters must be customized according to each particular construction site. To facilitate customization, the markup language, XML, is utilized. XML identifies objects and their parameters by using pre-defined tags, which are compatible with JavaScript functions. Sample code for hotspot customization and the VIFITS software structure are shown in Fig. 5. The VIFITS software structure is designed with six groups: database, functions, hotspots, layout, main modules, and general core framework with the start HTML file. In the sample code, the hotspot is customized in terms of visible parameters and reaction parameters. Visible parameters are obtained by selecting a value for each corresponding label (e.g., align, width, height, bgcolor, and bgalpha). The reaction is programmed by defining feedback for all possible actions captured through the user peripherals such as the mouse and keyboard. Since function customization is general not a daily user operation, a third-party XML editor is used (instead of dedicated components) with VIFITS (e.g., the Oxygen XML editor [30]) to reduce the complexity and performance of the VIFITS system.

6. Case study

To identify the advantages and limitations of the proposed system, a VIFITS prototype was developed and trials were carried out by educators and students in a fourth-year building construction class. As shown in Fig. 6a, the main page of VIFITS consists of: (1) a projection area, where users can manipulate and interactively experience virtual field trips in the VIFITS system; (2) a sidebar menu, which contains three groups such as user information (brief information, account management, and learning record), main modules (SID, FTE, and SKA), and key support functions (zoom in/out, autorotation, volume, and framework introduction); (3) a chat room, which provides a communication medium for the educators and learners to discuss and share their thoughts and materials online; and (4) a VIFITS address with a default service port number, which can be accessed via any popular web browsers.

First, educators and students login to the VIFITS system via their own accounts on mobile devices. According to OSHA [31], falling from height has the highest rate of occurrence among construction's "Fatal Four" accidents. Therefore, the falling from height topic was chosen for the VIFITS



(a) VIFITS Main Page (b) Disseminating Safety Information

Fig. 6. VIFITS Main Page and SID Module.

prototype. To disseminate safety information, the educator instructs students to click on a SID function, and then open a building project introduction slide (Fig. 6b), which introduces the project safety information and key falling hazards in a virtual building in order to help learners briefly understand safety issues prior to virtually experiencing the site in the next step. As illustrated in Fig. 6b, while a video was demonstrating the falling accident during curtain wall installation from inside the building, the educator analysed the hazard case and emphasized the root cause of the accident due to improper installation of a worker's fall arrest system.

During the lesson, students discussed with their classmates, and raised questions to the educator for further explanation through the VIFITS chatroom. Students' usernames appear in line with their questions, answers, or comments in the chatroom to help learners keep tracking of ongoing discussions. Moreover, students could easily upload and share digital supporting safety resources (e.g., links to multimedia, files, and safety-related e-materials) through the chat room (Fig. 6b) to support their viewpoint about the accident and receive feedback from others. Through open discussion with supporting safety resources in VIFITS, learners were engaged in their learning of falling from height, which was introduced by the educator. The educator only moved to the next falling hazard once every student clearly understood the previous accident case.

Second, students use their own mobile devices to experience a virtual field trip in the interactive VIFITS by clicking on the FTE function, and then choosing a virtual high-rise building. Following the educator's guidance, students clicked on the first floor and then experienced the lobby of the virtual building based on the building classification (as shown on the left in Table 1a). Students used the touch screen functions of their mobile device to zoom in, zoom out, and rotate to exploring the lobby scene. In this case, the educator instructed students to navigate to a corner of the lobby to analyse a dangerous working condition where workers were installing a dampa ceiling by using a mobile scaffold. During the virtual field trip, stu-

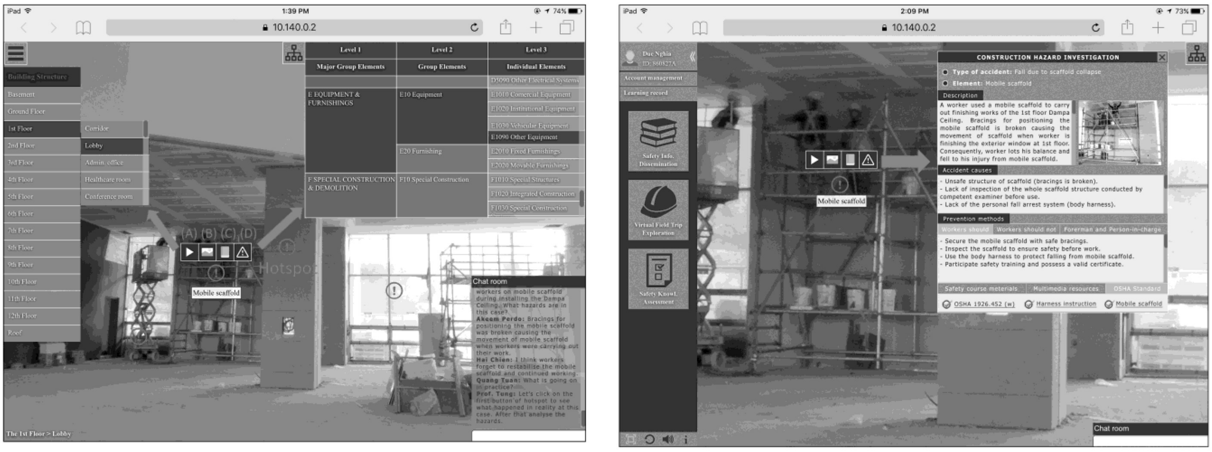
Table 1. Classification

(a) Building Classification

BUILDING CLASSIFICATION	
Level 1 (by floors)	**Level 2 (by spaces)**
Basement	Parking lots …
Ground Floor	Football yard …
1st Floor	Corridor
	Lobby
	Administration Office
	Healthcare room
	Conference room
…	…

(b) Uniformat Classification

UNIFORMAT CLASSIFICATION		
Level 1 (Major Group Elements)	**Level 2 (Group Elements)**	**Level 3 (Individual Elements)**
A SUBSTRUCTURE	A10 Foundation …	A1010 Standard Foundations …
B SHELL	B10 Superstructure	B1010 Floor Construction
		B1020 Roof Construction
	B20 Exterior Enclosure	B2010 Exterior Walls
		B2020 Exterior Windows
		B2030 Exterior Doors
	B30 Roofing	B3010 Roof Coverings
		B3020 Roof Openings



(a) Experiencing the virtual construction field trip (b) Investigating hazards

Fig. 7. Virtual Field Trip Experience.

dents clicked on hotspot attached to the building elements to open hotspot functions for investigating potential hazards related to this element. For example, as shown in Fig. 7a, when students clicked on a hotspot attached to a mobile scaffold, key functions of this hotspot (videos of the construction method, safety-related e-materials, animations of safe practices, templates for construction hazard investigation, etc.) assisted the learners in investigating hazards related to this mobile scaffold. Moreover, clicking on a hotspot highlighted the building classification (on the left of the screen) and Uniformat classification (on the right of the screen), allowing them to clearly visualize the building and remain aware of where they are in the virtual field trip.

Afterwards, students were required to analyse the working conditions for ceiling installation work using a mobile scaffold. As shown in Fig. 7b, students recognized a dangerous working environment, where the bracings used for positioning the scaffold were broken causing movement of the scaffold when workers were carrying out their work. However, workers forgot to re-stabilise the mobile scaffold with new bracings prior to continuing their works. Learners identified this potential falling hazard because the workers can lose their balance, and then fall from the mobile scaffold resulting in injury. After that, following the educator's instruction, students clicked on the video function of this mobile scaffold hotspot to play a video demonstrating a real construction method for dampa ceiling installation. In this case, a video portraying a mobile scaffold collapse when workers were carrying out the finishing work was presented, showing how a worker fell to his death from the mobile scaffold. While showing the video, the educator explained the root causes of accident due to a lack of stability of the mobile scaffold. Simultaneously, students could also easily discuss, raise questions and receive feedback during accident analysis. After students recognized the fatal falling consequences and analysed the root causes of the accident in the ceiling installation case, the educator showed an additional video demonstrating work safe practices with mobile scaffolds by clicking on safe practice function of the hotspot. During a video demonstration of safe practice, the educator emphasized OSHA safety regulations and their importance to prevent accidents. Through this, learners understood the accident case, recognized the fatal falling consequences, understood prevention methods for avoiding accidents, and then acquired knowledge.

To comprehensively analyse the falling hazard, students clicked on the construction hazard investigation function of the hotspot (Fig. 7b) to access a construction hazard investigation template. As shown in Fig. 8, the accident investigation template for a fall due to mobile scaffold collapse consisted of additional detailed safety information regarding the type of accident, description, root causes, and prevention methods. Moreover, the template provided many links to the digital safety course materials and multimedia resources for further investigation of the fall hazard. By clicking on OSHA 1926.452 (w) in the OSHA standard tab (Fig. 8), students also accessed this article in the OSHA website depicting the safety regulation, which must be complied with in order to avoid falling hazards due to mobile scaffold collapse.

In order to consolidate the acquired safety knowledge, students were required to explore the virtual high-rise building and investigate other potential hazards by themselves. During the virtual field trip experience and hazard identification, students discussed with other learners and the educator through the VIFITS chat room for further accident analysis

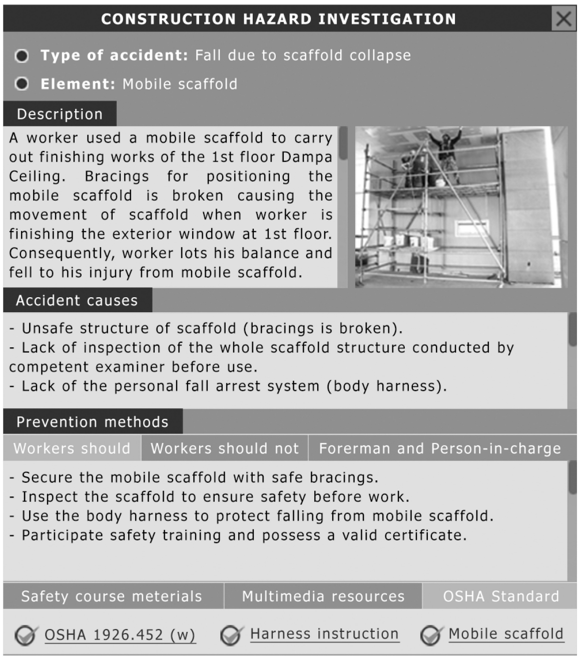


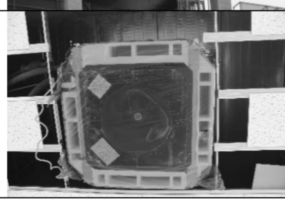
Fig. 8. Construction Hazard Investigation.

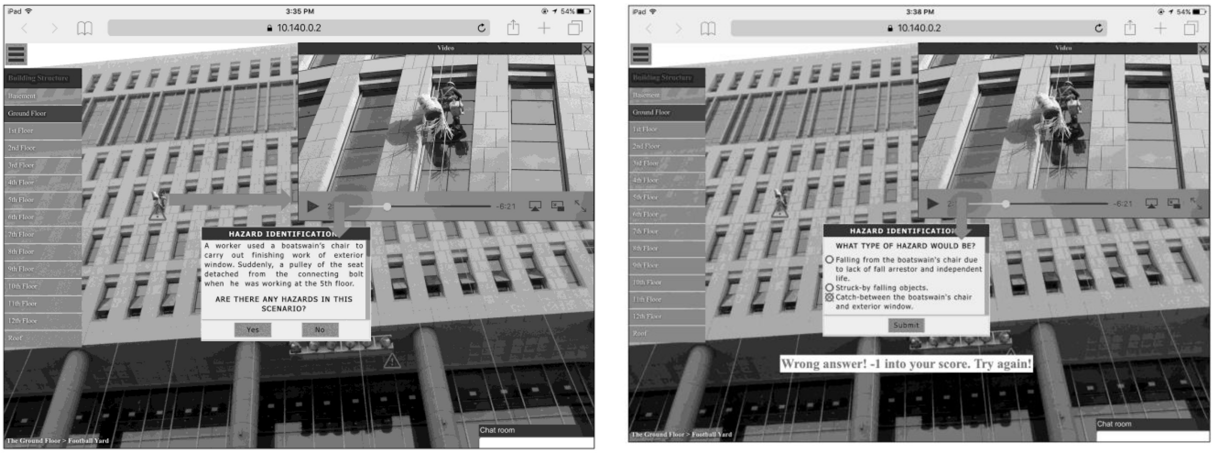
until they clearly understood the potential hazards and accident cases, which they found in the virtual field trip.

Finally, to assess the safety knowledge of learners obtained from the previous steps, SKA provided a testing simulation game, where students were required to investigate construction hazards. Students played the role of a safety engineer to identify potential hazards (Table 2) by navigating the exclamation signs within VIFITS to improve their hazard identification skills. Prior to site inspection, general site information was available within the virtual VIFITS environment to help students understand the current status of the inspected construction site.

After briefly understanding the virtual construction site, learners interactively explore the virtual construction field trip using their own mobile devices to navigate dangerous working conditions and identify construction hazards. Through mobile device touchscreen features, students easily navigated to an office at the fifth floor to identify the first

Table 2. Construction hazard investigation

IDs	Potential hazards	Element, Place	Description of accident case	Screenshot
1	Falling from a Boatswain's chair	Exterior window at the fifth floor	A worker used a Boatswain's Chair to carry out the finishing work of an exterior window at the fifth floor. During his work, a pulley suddenly disconnected with his seat causing the worker to fall to his death.	
2	Falling from a mobile scaffold	Ceiling at the ninth floor	Two workers collaborated to carry out the ceiling installation from a mobile scaffold positioned in the inclined level. Thus, to prevent scaffold movement, they installed the mobile scaffold in a level position by setting up a steel plate beneath the scaffold. After that, the mobile scaffold suddenly moved and then collapsed when the workers were working from the top of it. Consequently, two workers fell and suffered a serious injury.	
3	Falling from a temporary ladder	Light of the office at the twelfth floor	A worker used a temporary ladder to install a new light, however he fixed the ladder bracings carelessly. Consequently, the worker lost his balance, fell, and suffered an injury.	
4	Falling from height due to lacking temporary handrails at the edge of the floor	Finishing work on the roof of the building	Two workers removed all handrails and barriers assembled at the edge of the roof of a building in order to carry out the finishing work of the building façade. During roof installation, one worker slipped near the edge of the roof and fell down to his death.	
5	Electrocution when carrying out electrical works	Air-conditioner at the first floor	An electrician turned off the power system before installing the air-conditioner, however he forgot to lock the main power switch with a warning notice. Late on, while the electrician was working, another worker switched on the main power due to a lack of warning notice from the electrician. Consequently, he was electrocuted and then fell to his death.	



(a) Identifying Hazard (b) Identifying Type of Hazard

Fig. 9. Hazard Identification.

potential hazard. After that, they zoomed in and saw workers using a Boatswain's chair to carry out the finishing work for an exterior window outside the building. As shown in Fig. 9a, when students clicked on an exclamation sign tagged on this exterior window, a new window opened up a video demonstrating a construction method for carrying out the finishing work of the exterior window by using a Boatswain's chair. While the video was playing, the first question that appeared on the screen asked "ARE THERE ANY HAZARDS IN THIS SCENARIO?" (Fig. 9a), and the students answered by selecting Yes or No. In the case where students answered incorrectly, a reply notification announced "WRONG ANSWER! MINUS -1 INTO YOUR SCORE. TRY AGAIN" along with an audio alarm. In this step, students are required to re-answer the question until they answered correctly. After finishing the first question, students moved to the second multiple-choice question entitled "WHAT TYPE OF HAZARD WOULD BE?" (Fig. 9b). Similarly, students can only move to the next question once they finish this task with the right answer. Thereafter, students answered a third multiple-choice question for identifying the root causes of the accident, and then moved to the next step after submitting the correct answer.

In order to help students thoroughly understand the identified hazards as well as accident prevention methods, students are required to move to the step of Job Hazard Analysis (JHA). In this step, a JHA form is available for learners to fill out the type of accident, root causes, and sequence of safe practice. (Fig. 10). After finishing this form and submitting it to the VIFITS system, the correct answers of the JHA form will pop up in a red colour to help learners understand the appropriate prevention methods. When learners finished all steps of inspecting this hazard, the exclamation sign tagged on this exterior window disappeared from VIFITS screen.

After inspecting the first construction hazard, students then interactively navigated the virtual building to investigate other potential hazards. When the five construction hazards assigned by the educator were inspected by the students, a "Congratulation" notification (Fig. 11a) popped up immediately to inform learners about their scores for hazard inspection job. During the test, a digital clock on the top right side of the VIFITS interface (Fig. 11a) showed the remaining test time. The time constraint encouraged learners to work attentively to address the hazard inspection activities as fast as possible. All remaining hazards that the students did not identify within the allocated time were scored as zero. Moreover, VIFITS auto-

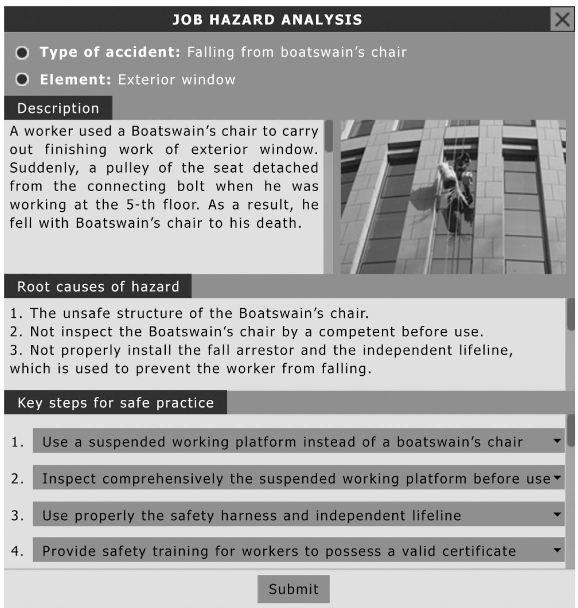
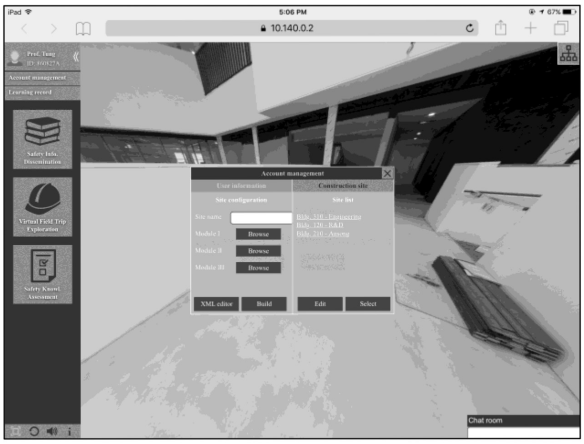


Fig. 10. Job Hazard Analysis.

(a) Assessing learner's performance



(b) Managing the virtual field trips

Fig. 11. User's Assessment Feedback and Virtual Field Trip Management.

matically recorded the hazard identification stage to help students review their performance and support the educator for further student evaluation. As shown in Fig. 11a, the learners could immediately view their scores after finishing the testing game. Furthermore, they could request further explanations regarding testing results by clicking on the feedback function.

As illustrated in Fig. 11b, VIFITS provides a virtual field trip management tool for admins to add, delete, and update many virtual construction field trips for mobile construction safety education. Through this, learners can experience different kinds of construction projects to improve safety knowledge and skills prior to entering the construction industry.

7. Evaluation

7.1 Evaluation scheme

In order to determine the pedagogic effectiveness and limitations of the proposed VIFITS system, an evaluation scheme comprised of the following two stages is proposed: VIFITS usability evaluation and VIFITS effectiveness evaluation were deployed, as depicted in Fig. 12.

In the first stage of evaluation, the VIFITS usability evaluation was conducted based on a VIFITS prototype, in which educators, construction managers, and students directly experienced the virtual field trip by using their own mobile devices. The virtual construction field trip was delivered as part of a supplementary course of a

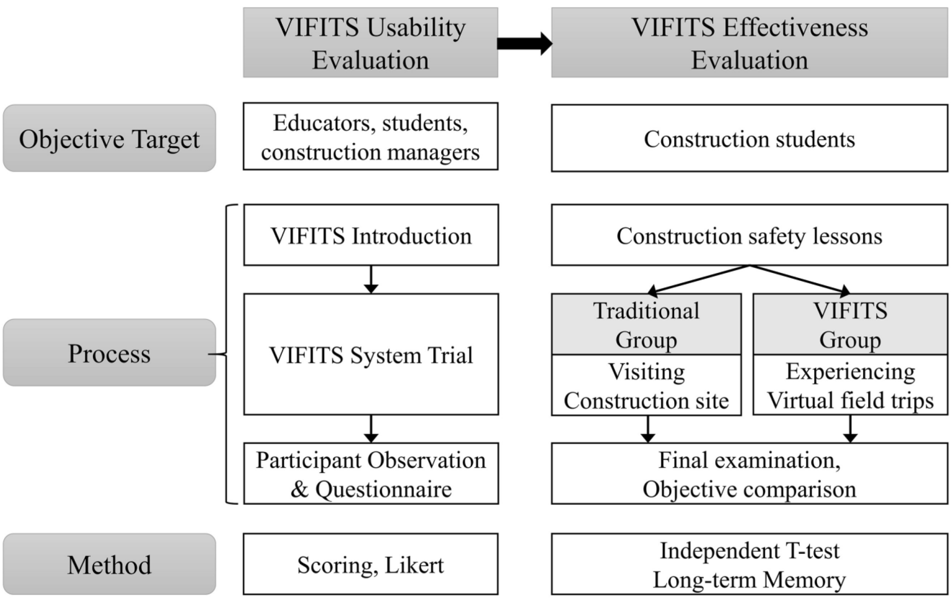


Fig. 12. VIFITS evaluation scheme.

building construction class. Following the learning steps of VIFIT framework, participants logged in to the VIFITS prototype with their own account, and then experienced virtual field trips. After a short break, these participants were interviewed and required to answer questions about the VIFITS usability according to the following criteria [4, 9, 10, 32]: (1) comfort of using a mobile device: considering the learner's comfort and how well participants executed tasks within VIFITS; (2) ease of navigation: focusing on how easily learners can navigate the virtual field trip through the system interfaces, designed tasks, and functions; (3) real-world visibility: focusing on how well the VIFITS system can represent a real construction site; (4) effectiveness in visualizing safety contents; (5) interactiveness with the virtual environment: considering how interactive the system features are; and (6) motivation and engagement in learning construction safety.

The second stage of VIFITS effectiveness evaluation focused on the objective comparison of learners' safety knowledge between the VIFITS method and traditional method. The effectiveness evaluation of this study tests hypothesis that students who learn with VIFITS acquire more safety knowledge than those who learn with traditional methods. First, the educator delivered construction safety lessons to undergraduate construction students in a classroom. After the lesson, these students were randomly divided into two groups: the VIFITS group and the traditional group. Students in the VIFITS group experienced virtual field trips based on the proposed VIFITS system, while traditional group visited a real construction jobsite. After the field trip, a final paper-based examination was carried out for both groups to objectively compare the learners' safety learning outcome based on the VIFITS and traditional approaches. Through this, the safety knowledge of learners can be evaluated the short-term impact of VIFITS. Furthermore, long-term safety knowledge retention would be assessed after over six months in order to comprehensively evaluate VIFITS effectiveness.

7.2 Evaluation result

First, interviews and questionnaires related to criteria for usability evaluation were conducted with five educators (from Chung Ang University in Korea; Ton Duc Thang University and Hochiminh University of Technology) and fifteen Korean and Vietnamese construction managers after they experienced the VIFITS prototype. Moreover, a system trial was also implemented in the building construction class in order to evaluate VIFITS usability in terms of the students' perspectives. Educators instructed thirty undergraduate construction students to experience the virtual field trip within an interactive VIFITS environment based on their own mobile devices. After that, interviews and discussions were conducted with students to rate the usability criteria based on a Likert scale (from 1 point for strongly disagree to 5 points for strongly agree). Preliminary results demonstrated that participants recognised VIFITS is a powerful pedagogical tool for improving construction safety education. Educators and construction managers emphasized the advantage of VIFITS for overcoming limitations of real construction field trips.

In detail, as shown in Fig. 13, participants were comfortable using their own smart mobile devices to experience virtual field trips through the VIFITS system. Due to the ubiquitous nature of mobile device ownership and web-based systems, they agreed that VIFITS can assist learners in studying construction safety education anytime and anywhere. Moreover, students emphasized that the VIFITS design was intuitive, and they could easily navigate virtual buildings in the proposed system by using their own fingers to interact with mobile devices. Functions and tools designed in VIFITS are friendly and common use as popular applications for smart devices, therefore it is easy for learners to explore the virtual field trips and investigate hazards to acquire safety knowledge. Learners using mobile devices with larger screen (iPad, tablets, etc.) prefer to learn more than those with small screen mobile devices (iPhones). However, few learners stated that it was a bit difficult for them to navigate the virtual field trips using a small screen. Furthermore, participants agreed that VIFITS can well represent the real-world visibility of construction sites. Through functions of the virtual field trip management (Fig. 11b), VIFITS can assist learners in experiencing field trips for different kinds of construction projects to obtain safety knowledge due to a lack of time and resource limitations to organise real field trips. For effectiveness in visualizing safety contents, participants agreed that VIFIT visualisations ran smoothly, providing learners with clear visualizations of not only digital safety contents but also components without glitches. Students emphasized that interactiveness is a prominent advantage of VIFITS because they easily used their mobile devices to directly interact with the virtual field trips, as well as digital safety contents embedded in the virtual building in order to obtain safety knowledge. They stated that the interactive features of VIFITS engage them to learn safety lessons as well as motivate them to fully experience the virtual field trips.

Second, an objective evaluation of VIFITS effec-

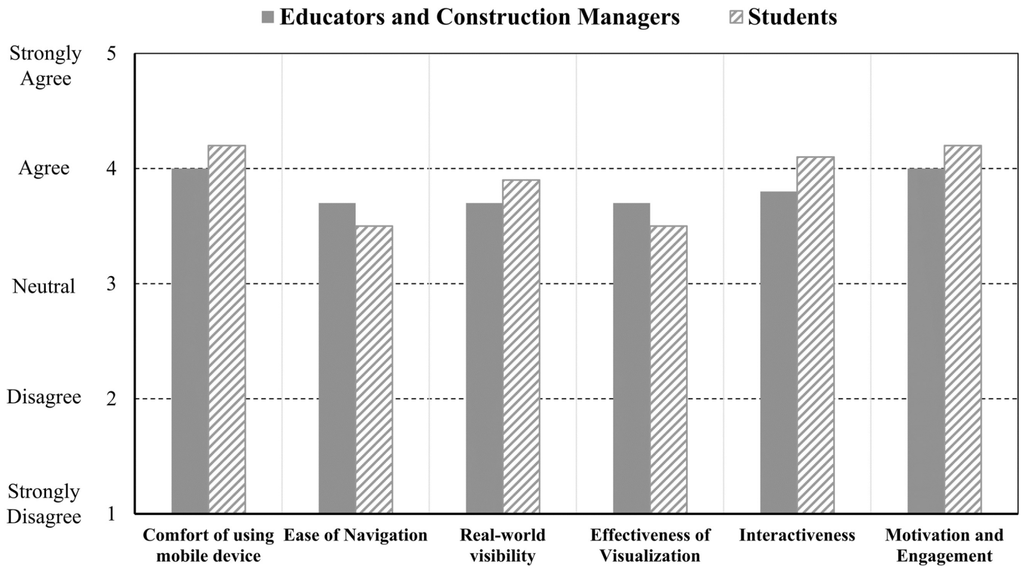


Fig. 13. VIFITS usability evaluation.

Table 3. Group Statistics

Paper-Based Test				
Education Method	**Number of Students**	**Mean**	**Standard Deviation**	**p-value**
VIFITS Group	30	80.33	3.46	0.037
Traditional Group	30	77.83	5.36	

tiveness was implemented in the real building construction class with sixty undergraduate students in order to measure the learner's learning outcomes. First, construction safety lessons were delivered by the educator to the fourth-year construction students in the classroom. After the lesson, these sixty undergraduate students were randomly divided into two groups, the VIFITS group and the traditional group. Thirty students in the VIFITS group experienced the virtual field trips based on the VIFITS system, while thirty undergraduates in the traditional group visited a real construction jobsite. Subsequently, sixty students were required to do a final paper-based examination (20 multiple-choice questions with a total score of 100) related to the safety lessons. To objectively compare learner's safety learning outcomes between the VIFITS and traditional approaches, an independent T-test model was developed to determine whether the score means between the two groups are statistically significantly different. The null hypothesis was that the difference between the two group mean scores is equal to zero, while the alternative hypothesis was that the difference between two group mean scores is not equal to zero. The SPSS20 statistics software was utilized to analyse the learning score of the two groups at the 5% significance level. According to Table 3, the mean value and standard deviation are 80.33 and 3.46, respectively for the VIFITS method; and 77.83 and 5.36, respectively for the traditional method. Since the p-value of 0.037 is less than significance level of 0.05, the null hypothesis was rejected. Moreover, the mean score of the VIFITS group (80.33) was higher than the mean score of the traditional group (77.83). Therefore, it was concluded that students using the VIFITS system for learning construction safety had higher scores than those learning based on the traditional method. In other words, the proposed VIFITS system is more effective than the traditional approach. This objective effectiveness evaluation demonstrates that the proposed VIFITS system can assist learners in acquiring construction safety knowledge and improve construction safety education.

8. Discussion

In order to implement VIFITS, Civil Engineering Faculty needs Information Technology (IT) experts with technical expertise in web-based application development, especially in VR framework for developing the web-based 360VR platform. Regarding didactic contents, the educators with comprehensive field trip experience and professional safety knowledge in various types of construction projects are necessary. These educators play a key role to design safety educational contents and hazard-identification experiences needed to educate learners during field trips. Afterwards, IT experts will assist the educators to initiate and set up VIFITS. Subsequently, the system can be utilized without support from IT experts, since it enables educators or admins to upload new scenes, position objects as well as materials through function of construction site management in VIFITS (see Fig. 11b).

The virtual field trip scene developed in VIFITS includes only one captured camera viewpoint for each floor of the building. This limits the ability of navigating the whole scene, resulting in non-visible corners as well as far objects with low resolution. Therefore, in future research, it would be worthwhile to consider how to integrate multiple camera viewpoints of a floor or area to effectively represent non-visible corners of virtual buildings, and thus improve interactive navigation during virtual field trips. Furthermore, the recent proliferation of wearable devices such as VR-glasses presents major potential for both industry and education. Future VIFITS implementations will focus on adopting VR-glasses to improve the immersiveness and learning experiences of virtual field trips. In addition, the 360VR technology itself cannot provide float object interactions inner a virtual scene as a 3D model does. Fortunately, this disadvantage can be addressed by a combination of 360VR and the three.js framework [33], thanks to the emergence of web3D technology. Therefore, future research should explore the interoperability between real-world-based 360VR panorama environments and existing 3D objects, in order to provide learners with more captivating and interactive learning contents.

9. Conclusion

Construction sites are the most complicated and dangerous workplaces, resulting in fatal accidents and facing unexpected challenges to satisfy industry requirements. Therefore, construction projects require knowledgeable and competent professionals to ensure safety. Construction safety education at the tertiary level can play an important role in equipping students with concrete safety knowledge and promoting safety performance prior to entering the construction site. However, safety topics are not paid adequate attention in the usual construction curricula, and traditional pedagogic tools fail to provide practical experience and sufficiently engage students in acquiring safety knowledge.

This study proposes an innovative educational system for mobile construction safety education using a 360-degree panoramic virtual reality. The proposed VIFITS system provided an interactive learning environment for bringing construction field trips to the classroom in order to improve student's practical experience and safety knowledge. The VIFITS prototype is developed and the system usability is evaluated through questionnaires and interviews. Educators and professionals emphasized the prominent advantages of VIFITS, which overcome limitations of real construction field trips. Moreover, a comparison of learning outcomes was conducted, between the VIFITS and the traditional methods through paper-based examinations to objectively evaluate system effectiveness. Preliminary results reveal that VIFITS would be a powerful pedagogical method for effectively providing practical experience and safety knowledge to students and improving construction safety education. Despite comparisons between these two educational methods to objectively validate VIFITS, long-term safety knowledge retention should be assessed with a full-scale system, after six months for future work to comprehensively evaluate VIFITS effectiveness.

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